

# SYSTEM AND METHOD FOR AUTOMATED MEASUREMENT OF SOIL pH

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims benefit under Title 35, United States Code, Section 119(e) of U.S. Provisional Patent Application Serial No. 60/096,172, filed August 11, 1998.

## TECHNICAL FIELD OF THE INVENTION

The present invention relates to detecting the acidity or alkalinity of soil. More particularly, it relates to methods and devices for automatically collecting data on the acidity or alkalinity of soil at a number of places in a field.

## BACKGROUND OF THE INVENTION

Site-specific farming, or precision farming, is used today in order to improve crop yields, lower costs, and to protect the environment, by treating different parts of a given field according to their specific conditions, instead of treating the entire field according to the average conditions throughout. In this way, for example, lime can be applied only to areas of a field which have overly acidic soil, which reduces the costs of materials and labor, and avoids excessively alkaline soil from unnecessary liming.

Typically, data on soil properties, including pH, are gathered by collecting a number of soil samples and analyzing them in a laboratory. The standard laboratory pH test for a single soil sample requires mixing equal masses of de-ionized water and soil, stirring vigorously for five to ten seconds, letting the mixture stand for ten to thirty

minutes, and measuring the pH of the slurry using a calibrated pH meter. This process must be repeated for each sample. Furthermore, each sample must be individually packaged to keep it from being contaminated during transport from the field to the laboratory, and labeled or otherwise identified with the specific location from which it was collected.

Because of the difficulty and expense of collecting and analyzing samples in the field with laboratory analysis, the total number of samples that can feasibly be collected is limited. Consequently, the resolution of the data is limited, so that current methods generally produce values of soil properties for areas on the order of a hectare.

As will be appreciated by persons of ordinary skill in the art, soil pH may have significant variation within a field. Some fields have soil pH ranging from 5 to 8, with a coefficient of variation exceeding 10%. Combining soil samples over an area of 1ha leads to a loss of information about spatial variability, and doubts exist about the accuracy of interpolated maps from grid soil sample data. Therefore, persons of ordinary skill in the art will recognize that the variation in soil pH over the area of a single grid can greatly exceed the experimental error in measuring soil pH. The accuracy with which processes such as liming, which are indicated based at least in part on soil pH, can be prescribed is restricted primarily by sampling density. Consequently, crop productivity as a whole is restricted by sampling density. Thus, there is an ongoing need to develop systems and methods to decrease the cost of soil sampling and to improve the resolution of soil property maps. The present invention is directed toward meeting this need.

## SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for automatically measuring soil pH in the field. An apparatus is disclosed, suitable for a standard tractor to tow, which will automatically measure soil pH at a relatively large number of places throughout a field. Also disclosed is an apparatus for automatically measuring the soil pH at a relatively large number of places throughout a field, including a device for simultaneously measuring the position of the apparatus, in order to automatically create a soil pH map.

In one form of the invention, an apparatus for automatically measuring the pH of soil at a relatively large number of places in the field is disclosed, comprising a chassis suitable for towing by a standard tractor; a plurality of wheels; a tank for holding water; a compressed air tank; at least one shank for exposing the soil at the desired sampling depth; at least one pH sensor, each including at least one probe; a probe assembly for each probe, including a sampling platform for collecting soil from pre-selected soil depths and bringing it into contact with the probe, an actuator for moving the sampling platform between an extended position in which a soil sample is collected and a retracted position in which the soil sample is in contact with the probe, and one or more nozzles connected by hoses to the tanks of water for cleaning the probe between measurements by directing water onto it; and an onboard computer for collecting and storing the data.

Another form of the invention includes an apparatus for automatically creating a map of the pH of soil in a field, comprising an apparatus for automatically measuring the pH of soil at a relatively large number of places in the field, and a sensor for continuously

detecting the position of the apparatus to allow each pH measurement to be automatically recorded in conjunction with the location of the soil which was measured.

Another form of the invention includes a method for measuring the pH of the soil at a relatively large number of places throughout a field, comprising: providing an apparatus for automatically measuring the pH of soil at a relatively large number of places in the field, including a chassis suitable for towing by a standard tractor, a plurality of wheels, a tank for holding water, a compressed air tank, at least one shank for exposing soil at the desired sampling depth, at least one pH sensor, each including a probe, a probe assembly for each probe including a shank for controlling the location of the probe assembly relative to the surface of the ground, a sampling platform for collecting soil from pre-selected soil depths and bringing it into contact with the probe, an actuator for moving the sampling platform between an extended position in which a soil sample is collected and a retracted position in which the soil sample is in contact with the probe, and one or more nozzles connected to a reservoir of water for cleaning the probe between measurements by directing water onto it, and an onboard computer for collecting and storing the data; selecting a depth at which soil pH measurements will be made; selecting a speed corresponding to the desired distance between locations for pH measurements; and towing the chassis through the field at the selected speed to collect data for a number of places throughout it.

Another form of the invention includes a method for creating a relatively high resolution pH map for a field, comprising: providing an apparatus for automatically creating a map of the pH of soil in a field; selecting a depth at which soil pH measurements will be made; selecting a speed corresponding to the desired distance

between locations for pH measurements; and towing the chassis through the field at the selected speed to collect data for a number of places throughout it.

One object of the present invention is to provide a unique apparatus for creating relatively high resolution pH maps. Other objects and advantages of the present invention will be apparent from the following description.

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## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of an apparatus for automatic measurement of soil pH according to the present invention.

FIG. 2 is a side elevational view of further details of the probe assembly shown in FIG. 1.

FIG. 3 is a side elevational view of the sampling platform shown in FIG. 1.

FIG. 4 is a schematic diagram of an apparatus for automatic measurement of soil pH having multiple probe assemblies.

FIG. 5 is a plan view of a field showing the relative positions of pH measurements made according to the standard method and the present invention.

FIG. 6 is a plan view showing the relative positions of certain parts of the apparatus shown in FIG. 1.

## DESCRIPTION OF THE PREFERRED EMOBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described processes, systems, or devices, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

Referring to Fig 1, an apparatus 100 for automatically measuring the soil pH according to the present invention is shown. Apparatus 100 includes a probe assembly 110 affixed to a chassis 120. Chassis 120 has a forward side 121 and a rear side 122, corresponding to the direction in which apparatus 100 moves when collecting data. Chassis 120 is supported by one or more wheels 130, which are adjustably mounted thereto, so as to allow chassis 120 to be raised or lowered relative to the surface of the ground 131. A tow hitch 140 is affixed on the forward side 121 of chassis 120, so that the apparatus can be towed by a standard tractor 132 or other appropriate vehicle. A shank 150 is affixed to chassis 120 <sup>direction of forward</sup> directly in forward of probe assembly 110, and with the bottom edge of shank 150 positioned lower than the bottom of probe assembly 110 when the apparatus is not collecting data. A removable plate 180 is positioned parallel to the direction of travel, adjacent to the trailing edge of shank 150, and to the side of probe assembly 110. A top plan view of the shank 150/removable plate 180 arrangement is illustrated in FIG. 6.

(shown as 165 in FIG. 2)

3 A water tank 160 is connected by water hoses ~~165~~ to a water pump 167, which is in turn connected to nozzles (shown as 250 in FIG. 2) in probe assembly 110. In one embodiment, water pump 167 is a standard 12V water pump (such water pumps being commonly known in the art). A compressed air tank 170 is connected to an air cylinder (shown as 230 in FIG. 2) through air hoses 175. Preferably, water hoses 165 and air hoses 175 are affixed to chassis 120 at a number of places along chassis 120.

A location sensor 190 is affixed to chassis 120 or other convenient location. In one embodiment, location sensor 190 is a standard global positioning satellite (GPS) antenna.

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17 A computer ~~180~~ is affixed to chassis 120, and is telemetrically connected to water pump 167, air cylinder 230, location sensor 190, and a probe (shown as 240 in FIG. 2), and is programmed automatically to record pH measurements ~~made by probe 240~~ made by probe 240 and location measurements made by location sensor 190, to correlate pH measurements with the location at which they are made, and to control water pump 190 and air cylinder 230, as further described below. In an alternative embodiment, water pump 190 and air cylinder 230 are controlled by a separate computer.

Referring to FIG. 2, further details of probe assembly 110 for making periodic measurements of the pH of soil at a pre-selected depth is shown. The probe assembly 110 includes a sampling platform 210 affixed to a first shaft 211, which extends through a spring 214 and a mounting 218, discussed hereinafter. At least the top portion of first shaft 211 is threaded, and is engaged by a threaded nut 216. The bottom end of spring 214 abuts mounting 218, and the top end abuts a washer 219, which in turn abuts threaded nut 216. An adjustment piece 220 for adjusting the distance between the



threaded nut 216 and the air cylinder 230 is provided, comprising two parallel portions, each having a threaded through-hole 221, and a perpendicular portion. Through-holes 221 are oppositely threaded, with the bottom hole threaded appropriately to engage the threads on the top end of first shaft 211. First shaft 211 and an second shaft 212 engage oppositely threaded through-holes 221, so that the distance between shafts 211 and 212 can be increased or decreased by rotating adjustment piece 220 about the axis of shafts 211 and 212. Second shaft 212 passes through mounting 228, discussed hereinafter. The end of shaft 212 opposite to adjustment piece 220 is affixed to air cylinder 230.

Air cylinder 230 is adapted to actuate second shaft 212 (i.e. move the shaft 212 away from air cylinder 230) when air pressure is applied by compressed air tank 170 through air hoses 175. The range of actuation is at least about 5mm, and preferably does not exceed about 40mm. Air cylinder 230 is affixed to mounting 228. In one embodiment, the air pressure required to cause air cylinder 230 to actuate shaft 212 is 250kPa.

A probe 240 is affixed to the bottom end of a third shaft 241. At least the top portion of third shaft 241 is threaded. Third shaft 241 passes through a spring 242, mounting 218, and mounting 248. A threaded nut 246 engages the top portion of shaft 241, and abuts mounting 248. The top end of spring 242 abuts mounting 218, and the bottom end abuts <sup>mounting 218</sup> ~~probe 240~~. When correctly positioned, probe 240 is just above sampling platform 210 in its retracted position.

Nozzles 250 are connected to hoses 165, and are directed toward probe 240, so that when water is pumped from tank 160, streams of water contact probe 240.

Probe assembly 110 is affixed to chassis 120 by mountings 218, 228, and 248. Mountings 218, 228 are affixed on chassis 120 sufficiently closely to place spring 214 in compression when sampling platform 210 is positioned at least below the bottom edge of shank 150 by turning adjustment piece 220. Mountings 218 and 248 are affixed to chassis 120 sufficiently far apart so as to place spring 242 in compression when probe 240 has been positioned at least as low as the lowest position in which it might be used to make measurements. This allows spring 242 to hold probe 240 in position against jostling of probe assembly 110 during motion. The position of probe 240 can be adjusted by turning threaded nut 246. In one embodiment, when spring 214 is in tension, it will return sampling platform 210 to the retracted position when air cylinder 230 is at rest (deactivated). When air pressure is applied to air cylinder 230, the compression in spring 214 is overcome, and sampling platform 210 is moved to the extended position. In another embodiment, spring 214 retains sampling platform 210 in an intermediate position when no air pressure is applied to air cylinder 230, wherein the bottom of sampling platform 210 is above the bottom edge of shank 150.

Referring now to Fig 3., further details of the preferred embodiment of sampling platform 210 are illustrated. Sampling platform 210 comprises a tray portion 310, and support portions 320. In the preferred embodiment, tray portion 310 is lower in the middle than on the sides. In another embodiment, tray portion 310 is flat. In one embodiment, tray portion 310 is about 50mm wide, and less than 66mm long, relative to the direction of motion. Support portions 320 are affixed to bar 330, which is affixed in turn to shaft 211, so that sampling platform 210 is in mechanical communication with air

cylinder 230. In one embodiment, sampling platform 210 is about 150mm from the top of bar 330 to the bottom of tray portion 310.

In the preferred embodiment, probe 240 is the sensor of an Accumet Model 25 pH meter, which is operable to measure the pH of a soil sample when placed in contact therewith. In order to allow its measurement of the pH of the soil samples to stabilize, the probe must remain in contact with the sample for at least 5 seconds, and preferably for 6 seconds. Collection of the sample and cleaning of the probe between measurements can be accomplished in about 1.5 seconds. Therefore, the preferred period of a measurement cycle is about 8 seconds. As will be readily apparent to those skilled in the art, this permits a range of sampling densities to be used, by varying the speed at which the apparatus 100 is moved.

When measuring soil pH with apparatus 100, adjustably mounted wheels 130 are positioned so that the bottom edge of shank 150 is a distance below the point where wheels 130 contact the ground 131 corresponding to the desired depth of measurement, so that, when apparatus 100 is towed, shank 150 will remove soil above the selected depth forward of probe assembly 110, creating a trench of the selected depth. Removable plate 180 prevents upturned soil from falling back against probe assembly 110, potentially contaminating measurements or otherwise disrupting performance. FIG. 6 is a plan view, illustrating the relative position of shank 150, sampling platform 210, and removable plate 180.

Air cylinder 230 is adapted to actuate sampling platform 210 between at least two positions, including an extended position and a retracted position. In one embodiment, when air pressure is applied to air cylinder 230, sampling platform is moved to the

extended position, in which sampling platform 210 is brought into contact with the ground 131, and when air pressure is removed from air cylinder 230, compression in spring 214 returns sampling platform 210 to the retracted position, in which the soil sample is brought into contact with probe 240. In another embodiment, air pressure can be applied in two directions to air cylinder 230, one causing air cylinder 230 to move sampling platform 210 to its extended position, and the other causing air cylinder 230 to move sampling platform 210 to its retracted position. In this embodiment, spring 214 retains sampling platform 210 in an intermediate position when no air pressure is applied. In yet another embodiment, a variable air pressure can be applied to air cylinder 230 so as to cause sampling platform 210 to move to any position intermediate to the extended and retracted positions. Furthermore, those having ordinary skill in the art will recognize that any suitable linear actuator device may be used in place of air cylinder 230, such as a solenoid, stepper motor/lead screw, etc.

Prior to beginning measurement, sampling platform 210 is positioned by turning adjustment piece 220 so that when air cylinder 230 moves sampling platform 210 to its extended position it is 5mm below the bottom edge of shank 150. The tension in spring 214 is optionally adjusted by turning threaded nut 216. When the apparatus is moving, this will cause soil to be collected on sampling platform 210. Probe 240 is positioned by turning threaded nut 246 so that when sampling platform 210 is moved to its retracted position soil samples contained on the sampling platform 210 are brought into contact with probe 240.

While sampling platform 210 is extended, water is pumped by water pump 167 from tank 160 through hoses 165, and projected through nozzles 250 onto probe 240, so

as to remove remnants from the previous measurement which might otherwise contaminate the new sample. Preferably, water is projected under pressure of at least about 100kPa. By projecting water onto probe <sup>240</sup>140 while sampling platform 210 is extended, samples are collected simultaneously to cleaning probe <sup>240</sup>140, minimizing measurement cycle time. The operation of water pump 167 and air cylinder 230 is synchronized by computer <sup>199</sup>180, which controls the operations of both.

Computer <sup>199</sup>180 also records the position of apparatus 100 as measured by position measuring device 190 while sampling platform 210 is in the extended position. The pH measurement of this sample is recorded approximately 6 seconds later, just before the measurement cycle is completed, and is associated in the data storage device with the position of apparatus 100 when the sample was collected. In this way, the pH data is correctly identified with the position in the field from which the soil sample was taken, and not with the position of the apparatus <sup>100</sup>100 when the measurement is made, which is later in time, when it will have moved some distance from the sample collection location.

Referring to Fig 4, an alternative embodiment of an apparatus for automatically measuring soil pH having a plurality of probe assemblies 110 and corresponding shanks 150 and removable plates 180 is shown. As will be readily apparent to those skilled in the art, by placing multiple probes on a single apparatus, a wider strip of field can be measured at a given sampling density, reducing the number of passes needed to measure a given area. Optionally, probe assemblies 110 and shanks 150 are slideably mounted on chassis 120 to permit a variable sampling density. In one embodiment, shanks 150 are independently adjustable, to allow each probe assembly to measure the pH of soil of an independently selected depth. In another embodiment, shanks 150 and probe assemblies

110 are positioned in at least two rows perpendicular to the direction of motion, so that at least two probe assemblies will measure soil from the same strip of soil. In this embodiment, shanks 150 can be adjusted so that shanks in more rearward rows run deeper than those in more forward rows, so that pH measurements can be simultaneously collected for a three dimensional map. In the preferred embodiment, the more rearward rows of probe assemblies can be positioned a distance behind the more forward rows of probe assemblies corresponding to an integral multiple of the sampling interval, such that deeper measurements are made at nearly the same position at which the shallower measurements are made.

Referring now to FIG. 5, typical sampling densities which can be achieved according to the standard soil mapping methods and the present invention are compared. A field 500 is shown, in which the pH was measured using both the prior art method and the present invention. Manually collected measurements 520 show the positions of data points in a pH map created by the prior art method, wherein the sampling density is one measurement per .5 acres. Automatically collected measurements 540 show the positions of measurements made with the apparatus 100 and methods of the present invention, using a single-probe apparatus 100.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.